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ORIGINAL ARTICLE

# Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites

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**Abstract**

Water absorption restrains the mechanical performance of natural fibre reinforced matrix polymer. This paper aims to investigate the influence of water absorption on the different types of natural woven fibre reinforced with polyester resin. The water absorption and thickness swelling study were performed by an immersed composite sample in the distilled water for 30 days. The mechanical performance testing such as tensile testing, flexural and impact was performed on the single and hybrid composite. Based on the results obtained, water absorption of the single type and hybrid composite sample yield about 3–6%. Furthermore, the effect of thickness of swelling is at a minimum. The result of the tensile properties reveals that the layering size has more influence than the layering sequences. The flexural properties are likely to be affected by the type of fabric fabricated on the top. The results of the Charpy impact test show that there is possibly less variation for the value regardless of the layering sequence and the layering size. The water absorption drops the tensile strength about 12–27% and tensile modulus for 15–35% on the 30th day. The result shows that the resistance toward water absorption improved significantly toward hybridisation.

**Keywords** Natural fibre · Jute · Ramie · Roselle · Water absorption · Mechanical properties

## 1 Introduction

The natural fibre is attractive among the researcher because of its properties of being biodegradable, recyclable, non-toxic, low cost, low density and possessed considerable mechanical strength properties [1–5]. As discussed in the literature, natural fibre reinforced polymer composite is expected to generate a total of 2.1 billion dollars in the year 2010 and is expected to continue growing by 10% until it reaches about 8.77 billion in 2025 [6]. The uses of natural fibre composite experienced a constant growth rate of 13% for the past ten years, and the demand is expected to keep increasing [7]. The applications of natural fibre are wide, which consist of automotive, construction, furniture, aerospace and marine industries [8–10].

Nevertheless, demand for natural fibre is high, especially in the application of automotive manufacturing and structural applications. Worldwide recognised automotive manufacturing companies such as German carmaker BMW Group utilised any types of the natural fibre composite in their production [6]. It was shown that BMW Group used a tremendous amount of natural fibre, approximately 10,000 tons to be exact in the year 2004 [7]. Most of these natural fibre composite will be utilised to produce vehicle components like door panels, noise insulation panels and headliner panel [6, 11].

However, the drawback of using natural fibre as reinforcement in polymer composite as the outdoor application is due to its low resistance to water absorption. As defined by the researcher, water absorption is a diffusion process in which the

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water molecule transited through the material due to arbitrary molecule movement [12]. Typically, the water penetrates the composite through three (3) mechanism which involves diffusion of water molecules, capillary transport from the micro gaps between the polymer composite surface and the transport of microcracks in the matrix ascending from the swelling of the fibre [13]. The water absorption tends to produce a negative effect such as poor dimensional stability, micro-cracking and degradation of mechanical properties [14].

The behaviour of the water absorption on the mechanical properties of the natural woven fabric has been studied in previous research works [15, 16]. From previous works, numerous types of matrix polymers and types of woven fabric were utilised. Gupta and Srivastava [15] conducted a study of water absorption on the hybrid of jute-sisal, which was reinforced with epoxy resin. They found that the water absorption decreased with the implementation of the hybridisation. Further improvement of water absorption was obtained through the utilisation of alkaline treatment. Misnon et al. [16] conducted an experiment of water absorption on the hemp woven reinforced with vinyl ester. From all of the studies, it could be concluded that factors that contribute to water absorption of the composite are temperature, fibre volume or weight fraction, void, fibre orientation, interfacial bonding, diffusivity, fibre type and the area of exposed surfaces [17–19]. Mariatti et al. [20] suggested that the water absorption of one composite was significantly affected by the poor adhesion and void content. Nevertheless, the behaviour of woven jute hybrid reinforced composite when exposed to excessive moisture condition is still unknown and limited from previous literature.

This paper focuses on the study of water absorption of woven fabric of jute, ramie and roselle, which is reinforced with unsaturated polyester (UPE) composite while considering the difference of the layering size and sequence. Further analysis of the water absorption of the water composite was performed by determining the rate of diffusion coefficient, sorption coefficient and permeability coefficient. The mechanical properties (tensile, flexural and impact) of single and hybrid jute, ramie and roselle were also examined. Also, the influence of water absorption on the tensile properties is investigated.

## 2 Experimental

### 2.1 Material

The natural fibre used in this experiment are jute, ramie and roselle (as displayed in Fig. 1) in the form of 1/1 plain woven with a density of 1.30 g/cm$^3$, 1.44 g/cm$^3$ and 1.38 g/cm$^3$ respectively. The woven jute, ramie and roselle were supplied by Tazdiq Engineering Sdn. Bhd., Kuala Lumpur.

The UPE grade Reversol P9509 resin was selected as the matrix polymer. From the information provided by the supplier, the UPE has a density of about 1000–1500 kg/m$^3$. Methyl ethyl ketone peroxide (MEKPO) grade of Butonox-M50 was used as a hardener. The UPE resin and MEKPO were supplied by Impian Z enterprise, Kuala Lumpur.

### 2.2 Composite fabrication

The composite was fabricated using the hand lay-up method. The dimensions of the mould size that were utilised were about 300 mm (width)× 300 mm (length) × 3 mm (thickness). The bee wax was applied on the top, middle and bottom of the mould to ensure the composite plate could be removed quickly after the curing process is done. All thirteen [17] samples were prepared according to the formulation as shown in Table 1. The UPE resin was mixed with 1% MEKPO and was continuously stirred for about 3 min. Next, the mixed UPE resin was poured into the surface of the fibre. The roller was applied to make sure the resin was spread evenly on the surface of the woven fabric and to remove entrapped air. This process was repeated until the desired number of layers was obtained. All of the fabrics were arranged in the direction of 0°. From the label of the formulation, the first letter represents the top fabric placement; meanwhile, the last letter is the bottom placement. Finally, the weight of about 60 kg was placed on top of the mould and left for curing in the ambient temperature for 5–8-h duration. The composite plate was cut into respective dimensions as required by the standard.

### 2.3 Density and void content of the composite

The density of the laminated composite was measured according to the ASTM 1895. Seven of the replicated samples were measured to obtain the mass using the analytical balance. The volume was measured by using the Vernier calliper. Equation (1) applied to measure the density.

$$\text{Density}\left(\text{g/cm}^3\right) = \frac{\text{mass}}{\text{volume}} \quad (1)$$

The void content of the composite was determined according to the ASTM D2734 09. The determining of the void content helps to distinguish the difference between theoretical and experimental of the composite plate. The following Eq. (2) was applied to the obtained percentage of void content in the composite sample.

$$V_v = 100 - M_d\left(\frac{V_r}{d_r} + \frac{V_f}{d_f}\right) \quad (2)$$

where $V$ is the volume or weight fraction, $M_d$ is the measured density from the experimental and $d$ is the density. The subscripts $r$ and $f$ each represent resin and fibre.

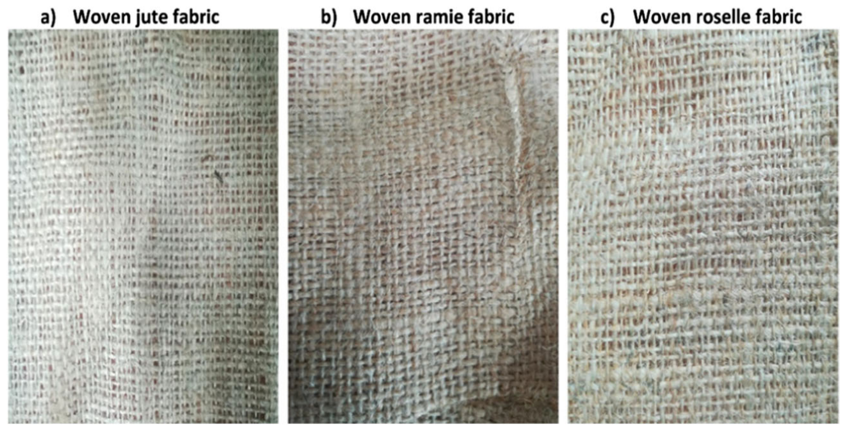


**Fig. 1** Plain woven fabric of jute, ramie and roselle

## 2.4 Water absorption and thickness swelling testing

The water absorption test was performed as referred to the ASTM D570-98. Distilled water was used to immerse the composite samples in the ambient temperature. The composite sample was then placed in the oven for a minimum of 2 h at a temperature of 80 °C [5, 21]. The weight of the composite sample was measured after cooling using an electronic analytical balance. The composite sample was then immersed in distilled water for up to 30 days. The composite sample was periodically removed from the water for weight measurement and immediately put back into the water. Before weighing the samples using electronic analytic balance, water on the surface of the samples was first wiped off. The calculation of water absorption was obtained using the equation below:

**Table 1** Formulation for fabrication

| Label for the composite sample | The weight of material fibre (jute) 1 (g) | The weight of material fibre 2 (ramie/roselle) (g) | Total weight of the fibre (g) | Total weight of UPE resin (g) | The total weight fraction of the fibre (w/w) | The weight fraction of the UPE resin (w/w) |
|---|---|---|---|---|---|---|
| UPE | 0.00 | 0.00 | 0.00 | 200.00 | 0.00 | 100.00 |
| JJ | 36.54 | 0.00 | 36.54 | 200.00 | 15.45 | 84.55 |
| RR | 0 | 45.63 | 45.63 | 200.00 | 18.58 | 81.42 |
| SS | 0 | 45.99 | 45.99 | 200.00 | 18.70 | 81.30 |
| JR | 20.34 | 25.56 | 45.90 | 200.00 | 18.67 | 81.33 |
| JS | 17.82 | 17.46 | 35.28 | 200.00 | 14.99 | 85.01 |
| JJJ | 70.11 | 0.00 | 70.11 | 200.00 | 25.96 | 74.04 |
| RRR | 0 | 65.07 | 65.07 | 200.00 | 24.55 | 75.45 |
| SSS | 0 | 58.05 | 58.05 | 200.00 | 22.50 | 77.50 |
| JJR | 49.68 | 15.84 | 65.52 | 200.00 | 24.68 | 75.32 |
| JJS | 41.94 | 24.12 | 66.06 | 200.00 | 24.83 | 75.17 |
| JRJ | 38.34 | 18.27 | 56.61 | 200.00 | 22.06 | 77.94 |
| JSJ | 37.89 | 15.84 | 53.73 | 200.00 | 21.18 | 78.82 |
| JRR | 23.04 | 45.72 | 68.76 | 200.00 | 25.58 | 74.42 |
| JSS | 18.81 | 44.73 | 63.54 | 200.00 | 24.11 | 75.89 |
| RJR | 20.16 | 40.95 | 61.11 | 200.00 | 23.40 | 76.60 |
| SJS | 25.29 | 39.96 | 65.25 | 200.00 | 24.6 | 75.40 |

$$\text{Mass change, } (\%) = \left|\frac{W_t - W_b}{W_b}\right| * 100 \quad (3)$$

From Eq. (3), $W_t$ represents the water absorption at an immersion time while $W_b$ referred to the water absorption at the baseline. The data obtained from the water absorption test was used for further analysis to obtain the type of diffusion mechanism for the water absorption, diffusion coefficient, and sorption coefficient described as in Eqs. (4)–(6):

$$\log\left(\frac{W_t}{W_\infty}\right) = \log(k) + n\log(t) \quad (4)$$

$$\text{Diffusion coefficient } (D) = \left[\frac{\pi(hm)}{4W_\infty}\right]^2 \text{ or } D = \pi\left[\frac{h}{4W_\infty}\right]^2\left[\frac{W_2 - W_1}{\sqrt{t_2} - \sqrt{t_1}}\right]^2 \quad (5)$$

$$\text{Sorption coefficient } (S) = \frac{W_\infty}{W_t} \quad (6)$$

$W_\infty$ in Eqs. (4)–(6) refers to the percentage of water uptake at infinite time. $W_t$ in Eq. (4) signifies the percentage of water uptake at time $t$. In Eq. (4), the $k$ and $n$ each represent the fraction between the sample and water in addition to its structural characteristics of the polymer network; meanwhile, $n$ refers to the transport mechanism. From Eq. (5), $m$ is a slope of a linear portion of the sorption curve and $h$ refers to the initial sample thickness in (mm).

The permeability coefficient is a value which refers to the combined effect between the diffusion coefficient and the sorption coefficient. The equation of the permeability coefficient is as shown in the following Eq. (7):

$$\text{Permeability coefficient } (P) = D \times S \quad (7)$$

**Table 2** Measured density and void content of the composite sample

| No. of sample | Type of the composite sample | Measured density (g/cm$^3$) | Void content (%) |
|---|---|---|---|
| 1 | UPE | 1.095 | 0 |
| 2 | JJ | 1.101 | 3.43 |
| 3 | RR | 1.157 | 0.58 |
| 4 | SS | 1.115 | 3.56 |
| 5 | JR | 1.153 | 3.48 |
| 6 | JS | 1.101 | 3.72 |
| 7 | JJJ | 1.144 | 1.19 |
| 8 | RRR | 1.179 | 0.16 |
| 9 | SSS | 1.134 | 2.68 |
| 10 | JJR | 1.160 | 0.13 |
| 11 | JJS | 1.132 | 2.54 |
| 12 | JRJ | 1.150 | 0.48 |
| 13 | JSJ | 1.076 | 6.75 |
| 14 | JRR | 1.114 | 4.57 |
| 15 | JSS | 1.108 | 6.18 |
| 16 | RJR | 1.085 | 6.32 |
| 17 | SJS | 1.097 | 4.14 |

The thickness swelling test was performed to determine the effect of water absorption on the dimensional changes of the composite samples when immersed in water for a specific duration of time. The thickness of the sample was measured using Vernier callipers before and after the immersion. The procedure of thickness swelling test was performed according to the ASTM D 5229 method. Equation (8) represents the equation for the thickness swelling test.

$$\text{Thickness swelling}, (\%) = \left|\frac{T_t - T_b}{T_b}\right| *100 \tag{8}$$

where $T_t$ is the thickness at immersion time while $T_b$ is the thickness before immersion time.

## 2.5 Tensile testing

In the paper, ASTM 3039 standard is followed for the tensile testing with its sample dimension. The test was performed using INSTRON 3369 universal testing machine with the crosshead speed of 1 mm/min. To obtain the most accurate result possible, each type of samples was tested seven times, and the average results were recorded.

## 2.6 Flexural testing

Flexural tests were performed by implementing the method of 3 points bend according to ASTM D 790 standards using Instron 3369 universal testing machine with the capacity of 5 kN and a crosshead speed of 1 mm/min. Eight samples were tested for pure jute composite and pure ramie composite. Then, eight samples were tested for each type of layering sequence hybrid composite and the pure polyester, respectively. The five most precise data from the eight data collected were used to calculate the average value for each type of composites.

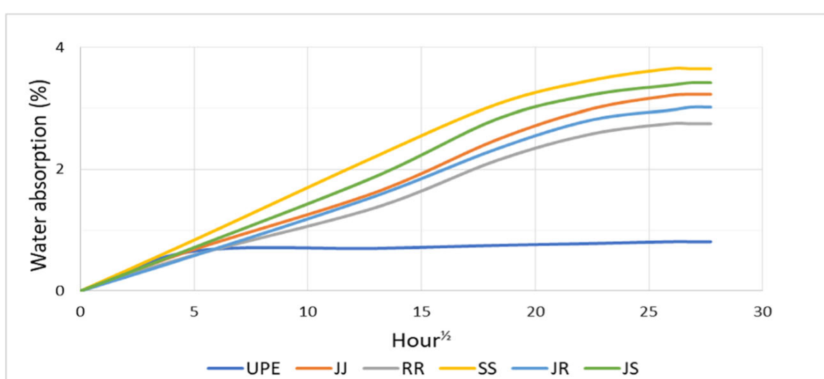


**Fig. 2** Water absorption of 2 layers of woven fabric over square root time (hours½)

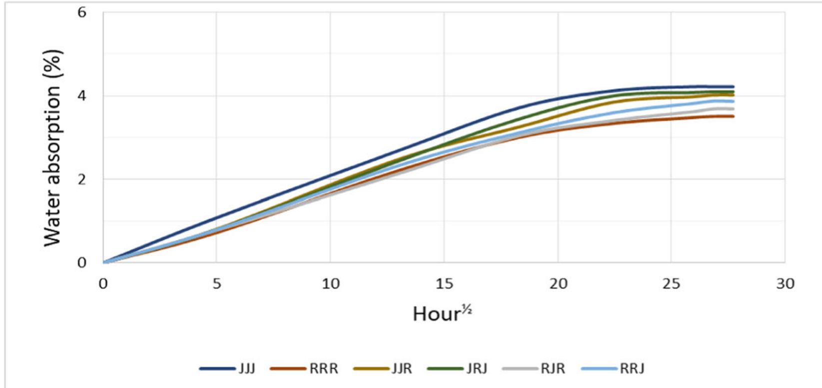


**Fig. 3** Water absorption of 3 layers of woven fabric for single jute, ramie and hybrid jute-ramie over square root time (hours½)

### 2.7 Charpy impact testing

The Charpy impact testing was conducted according to the ASTM D6110-10. The sample has a notch in the centre of the sample with a depth of 2.54 mm and an angle of 45°. The notch was prepared with the unique milling tool. Minimum seven (7) samples were prepared for each group of the composite sample.

## 3 Results and discussion

### 3.1 Density and void content

The data of density and void content of the plate that was obtained from the experiment are shown in Table 2. Void content presented in Table 2 is designated for the difference between the experimental and theoretical of the composite samples. The density of the composite plate is dependent on the content of the reinforcement and UPE. From the results obtained from Table 2, the density between composite with two layers and three layers is identical. The highest void content is obtained from a sample of JSJ (6.75%). The hybrid composite contains woven jute, and roselle poor compatibility resulted in higher void than woven jute and ramie hybrid composite. In overall, the average of void content on the two layers of the samples is at the minimum (2.95%) when compared to the three layers of composite samples (3.19%). The high content of fibre layers caused inefficient resin distribution reducing the resin-rich area in the composite. High void content in the laminate composite also reflected the inadequate adhesion between fibre and matrix phase, which lead to the poor performance of mechanical properties and promoting crack initiation and growth. Besides that, void distribution or void shape is an important parameter affecting the mechanical performance of the laminate composite. Nonetheless, the void distribution and void shape are unknown in the current study.

### 3.2 Water absorption

The percentage of water absorption for all of the samples is as illustrated in Fig. 2. The rate of water absorption varied and depended on the duration of immerses. As determined from Fig. 2, the water penetrated the composite sample abruptly in the first weeks and then gradually slows when reaching the third week of immersion. The water uptake reaches equilibrium between 28 and 30 days. Figures 3, 4 and 5 show the plotted percentage of water absorption over the square root time (hours).

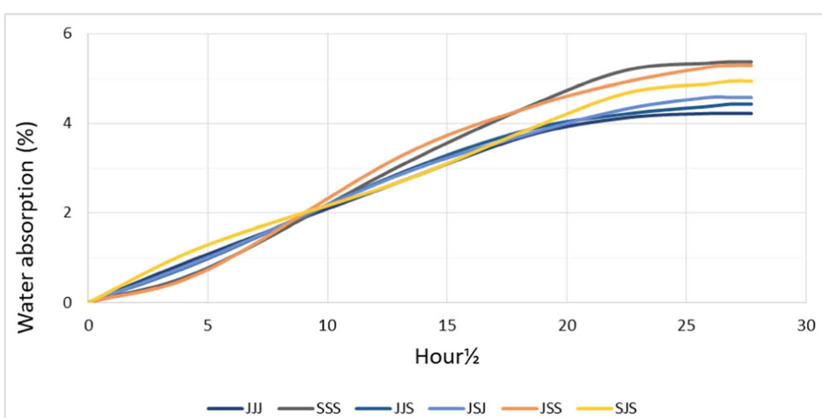


**Fig. 4** Water absorption of 3 layers of woven fabric for single jute, roselle and hybrid jute-roselle over square root time (hours½)

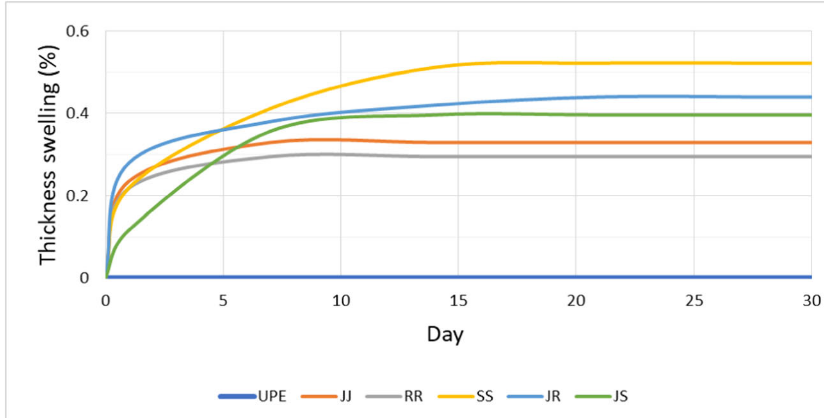


**Fig. 5** Thickness swelling for the two-layer composite and UPE sample

As observed in Figs. 2, 3 and 4, many factors are linked to the variations in the water absorption such as type of fibre, the composition of polymer and fibre and layering arrangement. By comparing the types of material, the water absorption is higher for the sample which contained roselle fabric. The behaviour of woven roselle fabric composite could be related to the higher cellulose and hemicellulose content in the composite. The higher content of cellulose and hemicellulose in the roselle fabric means the percentage of hydroxyl (-OH) and acetyl ($C_2H_3O$) group is higher, which is the principal contributors to moisture absorption.

Weight content which affects the water absorption could be determined by comparing the two-layer samples with the three-layer samples. The increase in the weight content and layering size surges the water absorption. However, the difference in the void content likely altered the water percentage of the sample [22]. Thus, the water which penetrated will fill up the void rapidly until the space becomes limited [22]. The location of the void content in the composite sample influences the percentage of water absorption. Thus, the porosity lies on the edge of the composite sample likely filled with a water molecule. The effect of layering sequence can be observed on the 3-layer laminated composite. The percentage of hybrid composite is almost similar regardless of the arrangement of the fabric.

Table 3 shows the linear kinetic diffusion, value of $n$ and value of $k$ mechanism for all of the samples. From the value of $n$ and $k$, water transport behaviour could be determined. There are three (3) cases of water transport which is the Fickian diffusion (cases I), non-Fickian diffusion and polymer relaxation–controlled diffusion (cases II) [23]. Table 4 summarises the water behaviour transport.

**Table 3** Linear equation, value of $n$, value of $k$ and R-square for the composite sample

| No. of sample | Sample abbreviation | Linear equation | Value of $n$ | Value of $k$ | R-square |
|---|---|---|---|---|---|
| 1 | UPE | $y = 0.1769x - 0.255$ | 0.1769 | 0.556 | 0.9941 |
| 2 | JJ | $y = 0.9368x - 1.3263$ | 0.9368 | 0.047 | 0.9931 |
| 3 | RR | $y = 0.9313x - 1.3168$ | 0.9313 | 0.048 | 0.991 |
| 4 | SS | $y = 0.8741x - 1.2244$ | 0.8741 | 0.060 | 0.9812 |
| 5 | JR | $y = 0.9836x - 1.3886$ | 0.9836 | 0.041 | 0.9916 |
| 6 | JS | $y = 0.9346x - 1.3136$ | 0.9346 | 0.049 | 0.9855 |
| 7 | JJJ | $y = 0.811x - 1.1314$ | 0.811 | 0.074 | 0.9742 |
| 8 | RRR | $y = 0.9264x - 1.293$ | 0.9264 | 0.051 | 0.9693 |
| 9 | SSS | $y = 1.1439x - 1.5952$ | 1.1439 | 0.025 | 0.97 |
| 10 | JJR | $y = 0.9442x - 1.3212$ | 0.9442 | 0.048 | 0.9757 |
| 11 | JJS | $y = 0.8841x - 1.2334$ | 0.8841 | 0.058 | 0.9664 |
| 12 | JRJ | $y = 0.9702x - 1.3541$ | 0.9702 | 0.044 | 0.9741 |
| 13 | JSJ | $y = 0.8944x - 1.2529$ | 0.8944 | 0.056 | 0.9794 |
| 14 | JRR | $y = 0.9299x - 1.3058$ | 0.9299 | 0.049 | 0.9817 |
| 15 | JSS | $y = 1.1511x - 1.6032$ | 1.1511 | 0.025 | 0.9571 |
| 16 | RJR | $y = 0.9144x - 1.2859$ | 0.9144 | 0.052 | 0.9842 |
| 17 | SJS | $y = 0.8105x - 1.1495$ | 0.8105 | 0.071 | 0.9932 |

**Table 4** Water transport behaviour

| Type of water transport behaviour | Slope | Time dependence | Composite sample |
|---|---|---|---|
| Less Fickian diffusion | $n < 0.5$ | $t^{1/2}$ | – |
| Fickian diffusion | $n = 0.5$ | $t^{1/2}$ | – |
| Non-Fickian (anomalous diffusion) | $0.5 < n < 1$ | $t^{n-1}$ | JJ, RR,SS, JR,JS, JJJ, RRR,JJR,JJS, JRJ, JSJ, JRR, JSS, RJR, SJS |
| Case II transport | $n = 1$ | Time independent | – |
| Super case II transport | $n > 1$ | $t^{n-1}$ | SSS |

The values of $n$ obtained for all composite samples are listed in Table 5. Most of the value of $n$ that was obtained lies between the range of $0.5 < n < 1$. In some cases, the value of $n$ obtained is greater than 1 ($n > 1$). Therefore, the diffusion mechanism of the produced composite sample follows the non-Fickian diffusion and super case II transport. For the non-Fickian diffusion, the diffusion and relaxation rates are almost equal. Meanwhile, in the super case II, transport penetrations of the water molecules are more significant than the relaxation process. The anomalous behaviour of natural fibre composite obtained in study is similar as reported by the other researcher [24, 25]. Nevertheless, only pure UPE exhibits less Fickian diffusion. The value of $n$ for the UPE is lower than the other composite samples, indicating that the addition of the woven fabric limits the movement of water through the UPE resin [26]. On the other hand, the value of $k$ represents the indication for interaction between water and materials [27]. The lower value of $k$ demonstrates that the composite sample has an excellent interaction with water.

**Table 5** Diffusion coefficient, sorption coefficient and permeability coefficient for a single and hybrid composite sample of woven jute, ramie and roselle

| Sample | Diffusion coefficient ($mm^2/s \times 10^{-8}$) | Sorption coefficient (g/g) | Permeability coefficient ($mm^2/s \times 10^{-8}$) | Percentage of absorption saturation point (%) | Void content (%) |
|---|---|---|---|---|---|
| UPE | 4.69 | 1.25 | 5.84 | 0.81 | 0 |
| JJ | 144 | 4.82 | 693 | 3.23 | 3.43 |
| RR | 134 | 4.74 | 636 | 2.75 | 0.58 |
| SS | 202 | 4.45 | 897 | 3.65 | 3.56 |
| JR | 123 | 5.30 | 654 | 3.02 | 3.48 |
| JS | 221 | 4.89 | 1080 | 3.42 | 3.72 |
| JJJ | 226 | 3.98 | 902 | 4.221 | 1.19 |
| RRR | 272 | 4.94 | 1340 | 3.51 | 0.16 |
| SSS | 272 | 7.16 | 1950 | 5.37 | 2.68 |
| JJR | 372 | 5.09 | 1890 | 4.02 | 0.13 |
| JJS | 415 | 4.61 | 1920 | 4.43 | 2.84 |
| JRJ | 304 | 5.26 | 1600 | 4.1 | 0.48 |
| JSJ | 229 | 4.65 | 1070 | 4.58 | 6.75 |
| JRR | 283 | 7.45 | 2110 | 3.87 | 4.62 |
| JSS | 237 | 4.79 | 1140 | 5.29 | 6.28 |
| RJR | 154 | 3.89 | 597 | 3.69 | 6.65 |
| SJS | 286 | 4.96 | 1420 | 4.94 | 4.69 |

Table 5 presents the value of the diffusion, sorption and permeability that was obtained from the experiments. As determined, the value for diffusion, sorption and permeability obtained is inconsistent with each type of samples. The different value could be explained via variation in the geometry of the composite sample and free volume in the woven fabric. On the overall, the values for the diffusion coefficient of the composite with 3 layers are greater than the 2-layer composite. Higher content of jute, ramie and roselle encourage made the water penetrate easier in the composite due to the hydrophilic nature. For pure UPE sample, the diffusion is slower compared to the composite samples due to water molecule hardly penetrate the crystalline region. The range value ($1 \times 10^{-8}$-$1 \times 10^{-6}$) for the diffusion coefficient obtained in the study is comparable to the previous research work [15, 16]. Based on Table 5, the composite sample contained sisal fibre has higher permeability coefficient compared to other types of composites.

### 3.3 Thickness swelling

The results of the thickness swelling are presented in Fig. 6, 7 and 8. On the overall, the effect of the thickness swelling is less compared to the weight increment. Low thickness swelling can be linked to the softening effect caused by water molecules that reduces the rigidity of the cellulose structure. The composite samples expand in the direction of vertical and horizontal when immersed in water.

The thickness swelling is varied on the layering size, layering sequence and type of materials. Among all of the factors, it seems that the type of materials affects the thickness swelling the most. As observed from the result obtained, the thickness swelling is more dominant on the composite sample containing roselle fabric. From Fig. 6, the thickness swelling of the SS composite is the highest compared to the other two layers of composite sample. A

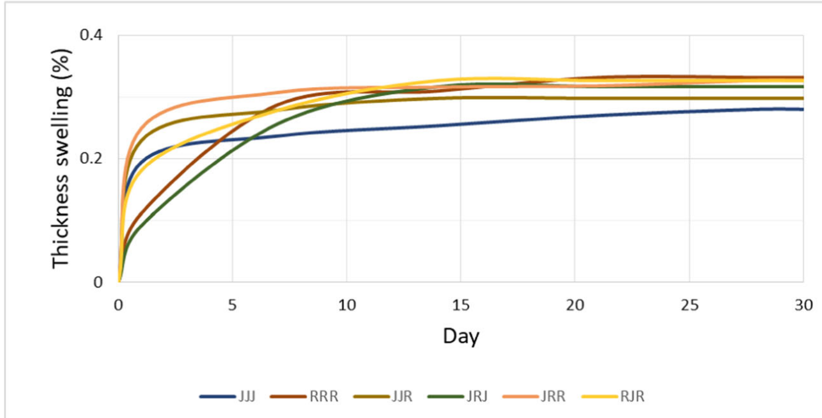


**Fig. 6** Thickness swelling for the three layers of single and hybrid for jute and ramie

similar pattern is experiential from the three layers of composite sample. There are substantial differences between the value of thickness swelling of the SSS compared to the single type composite of jute, ramie and hybrid jute-ramie. The typical thickness swelling of jute and ramie sample for two layers and three layers lies between 0.3 and 0.4%. The composite with a high weight content of the jute fabric yields lower thickness swelling. On the other cases, the dimension of the UPE sample remains unchanged throughout the experiment. The UPE resin is highly resistant to the water due to its hydrophobic nature.

### 3.4 Tensile properties

Figure 8 shows the bar chart for the tensile strength and tensile modulus for all of the samples. As observed from Fig. 8, the tensile strength of UPE strongly increased by the addition of the fabric woven of the jute, ramie and roselle. The two-layer woven fabric of jute, ramie and roselle improved the UPE to about 12–36% for tensile strength and 90–135%. Besides that, the three-layer composite roughly improves the tensile strength and tensile modulus of about 20–40% and 80–112%. Tensile strength and tensile modulus of the composite sample are dependent on the waviness or yarn crimp. In the composites sample, the crimped fibre in the woven fabric of jute, ramie and roselle tends to straighten out when the tensile load applied resulted in greater tensile properties. In both cases of different layering sizes, the woven jute sample produces the highest tensile strength when compared to woven ramie and roselle sample. In terms of tensile modulus, the woven ramie samples are less stiff than samples made by woven jute and ramie.

As determined in the experiment, the effects of hybridisation on the tensile strength and tensile modulus on the composite samples are at the minimal. The similar points were addressed in previous research work as shown by [28]. The hybrid jute-ramie and jute-roselle composites produce the tensile strength and modulus between those of pure jute, ramie and roselle composite. The effect of the stacking sequence on the hybrid composite is not significant because all the composites under tensile loading experience the comparable strain. Therefore, the tensile strength will mainly be affected by the fabric strength, modulus and fibre orientation, weight of volume content and interfacial adhesion [28, 29]. The values of the tensile strength of the samples are directly proportional to the content of the fabric with higher strength. The result of the experiment is homogeneous with results obtained from previous work [30, 31].

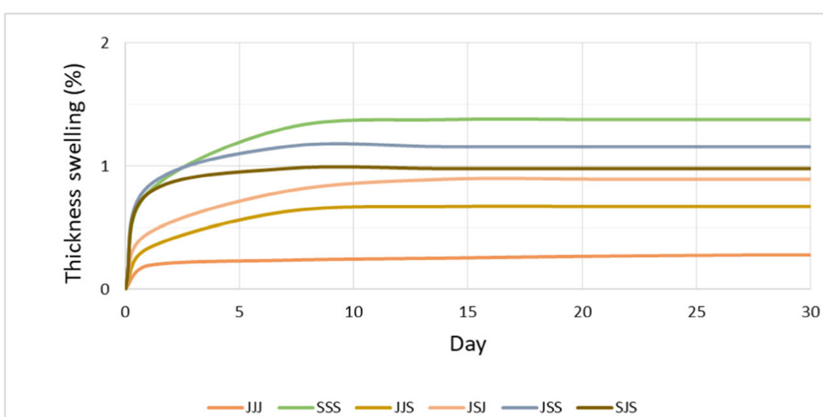


**Fig. 7** Thickness swelling for the three layers of single and hybrid for jute and roselle

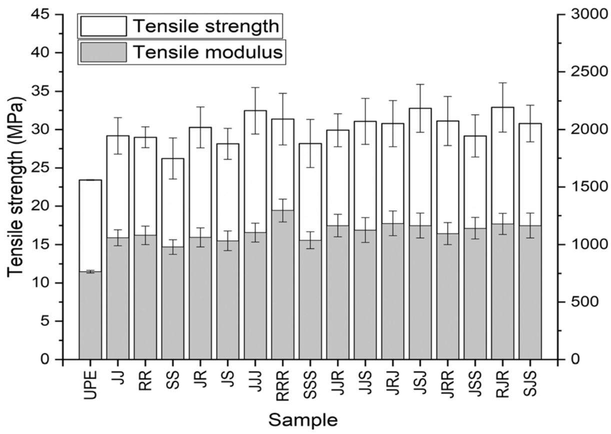


Fig. 8 Tensile strength and tensile modulus of the sample

## 3.5 Flexural properties

The mean flexural strength and flexural modulus obtained from the experiment are presented in Fig. 9. Similar patterns as tensile strength and tensile modulus were observed for the flexural strength and flexural modulus. Most of the samples recovered the flexural strength of UPE up to 24–40% and 38–55% for the flexural modulus. The performance of the flexural strength of the sample varies depending on the layering size, layering sequence, type of woven fabric and thickness of the sample.

The increase of the layering size gives a significant effect on both the flexural strength and the flexural modulus of the samples. All of the flexural strength and flexural modulus have a linear relationship with the increment of the layering sizes. Thus, increasing the number of layering size improved the flexural properties of the composite. The results obtained are analogous to many findings found from previous works [32, 33]. As observed in the result, the value of flexural strength for the two-layer composite is about 26.22–29.18 MPa, meanwhile for the three-layer composite 28.18–32.90 MPa. The increase of the layering size roughly improves the flexural strength to about 7–12%. The increase of the flexural strength indicates the ability of the sample to resist bending. The layering sizes also result in good effects on the stiffness of its counterpart. The sample becomes more flexible as the flexural modulus increases to about 4–19%. The value of the flexural strength for the hybrid composite displayed showed not much difference from the monolithic composite. However, the hybrid of the jute-ramie composite is better than the hybrid of jute-roselle in both cases for the two-layer and also three-layer composites. In the study, the effect of layering sequence in the hybrid composite is confirmed for strongly affected flexural strength and modulus as shown in the previous research work [34, 35]. As highlighted by the researcher, the flexural strength of the composite is controlled by the extreme layers of the reinforcement [34, 35]. Therefore, the woven fabric with higher strength like jute and ramie yields higher flexural strength when placed on the top.

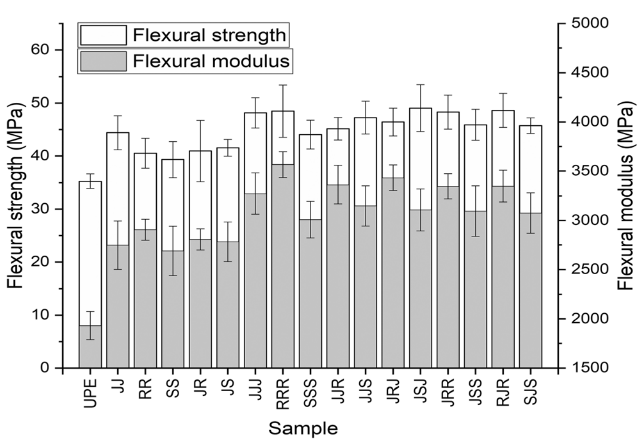


Fig. 9 Flexural strength and flexural modulus of the sample

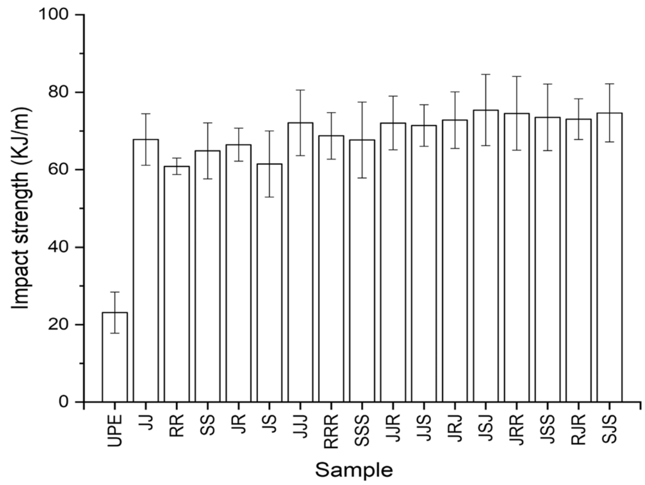


Fig. 10 Impact strength of the composite sample

## 3.6 Impact properties

Figure 10 shows the results obtained from the Charpy impact testing of the composite samples. The addition of the woven fabric of the jute, ramie and roselle recovered the impact strength of the pure UPE resin. Most of the samples showed improvement to the impact of the strength of the pure UPE resin for about 160 to 225%. The samples of the JSJ (75.4 KJ/m$^2$) yield the highest for the impact on strength. The increase of the impact strength for the composite sample is due to the role of woven fabric jute, ramie and roselle as a stress transferring medium and preventing a crack formation. Also, the interlocking structures in the woven fabric provide a higher resistance to the impact stress.

The layering size critically altered the Charpy impact strength. Also, as determined in the study, the thicker (3 layers) composite sample will give better impact resistance

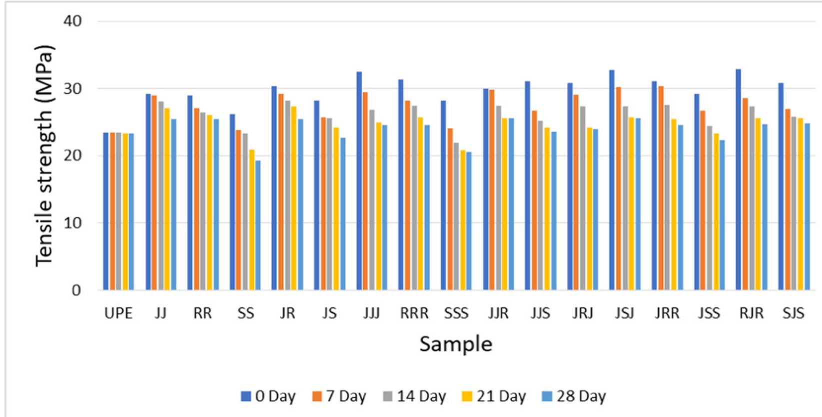


**Fig. 11** Effect of the water absorption on the tensile strength of the sample

and distribute-redistribute better load compared to the thinner (2 layers) composite sample. Effect of layering sequence on the composite sample is also determined in the study. On overall, the hybrid composite sample improved impact damage resistance than the monolithic composite sample. As determined, the hybrid jute-roselle performed better when compared to the hybrid jute-ramie composite. The woven jute-roselle aided in lowering the possibility of the overall failure and at the same time expanded the impact damage of resistance. On the overall, since the direction of the blow is from the side, the location of the woven fabric does not much influence the performance of impact strength.

### 3.7 Effect of water absorption on the tensile properties

Figures 11 and 12 show the results for the tensile strength and tensile modulus for single and hybrid composite reinforced with polyester under dry and wet conditions. Most of the previous research shows that tensile strength deteriorated when exposed to excessive moisture [22, 36]. Therefore, the results obtained from the study are coherent as previous work.

In the initial phase (1–7 days), the tensile strength for all composite sample drops about 1–15%. After 28 days, the tensile strength of all of the composite samples drops as much as 12 to 27%. Most of the composite experienced greater loss of average tensile strength values of the first and second weeks. On the other hand, the tensile modulus for two-layer samples was reduced to about 5–15% after 7 days of water immersion and kept reducing until it reached 15–32% on the 28th day. Nevertheless, the tensile modulus reduces drastically for the three-layer composite, especially for the first 7 days (9–20%). The higher percentage is dropped for a higher number of layering size of fabric woven composite samples. Reduction of tensile modulus is shown that the composite sample is becoming softer and ductile primarily due to plasticisation effect which increased strain.

The pure UPE resin samples are unaffected when exposed to excessive moisture. UPE resins effectively reduce the penetration of water into the interface through the surface. The percentage drop of the tensile properties for the entire composite sample can be related to the percentage of water absorption. Among all of the composite samples, the single sisal with three-layer composite and highest moisture absorption suffers the most tensile property drops. Furthermore, the relationship between the moisture absorption and tensile properties is also

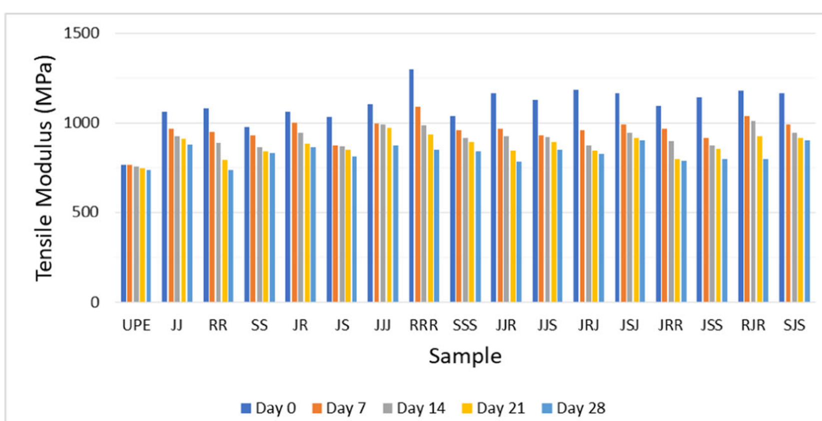


**Fig. 12** Effect of water absorption on the tensile modulus of the sample

obvious on the hybrid composite sample of JSS. The composite sample with a higher content of roselle is more vulnerable to moisture attack. Thus, the roselle fabric possesses low resistance to moisture than the woven fabric of jute and ramie.

The tensile properties for all the samples were rapidly weakened when immersed in distilled water primarily due to the reduction on fibre/matrix interfacial in the composites. The water molecule which enters the composite via crack and void caused degradation of the bonding between the fibre and matrix phase through the hydrolysis reaction of unsaturated groups within the resin [37]. The water molecule is also producing a crack in the polymer matrix causing disruptions for load transfer from matrix to fibre in the composites.

## 4 Conclusion

This experiment focuses on the influence of water absorption on the mechanical properties (tensile, flexural properties and impact) of single and hybrid woven composite reinforced with UPE resin. The key finding in the experiment is described as follow:

(1) Immersion of the composite samples does alter weight and thickness, especially in the initial phase of immersion (1–7 days).
(2) Single jute fibre composite is superior in the tensile strength and impact strength properties for 2- and 3-layer composites.
(3) The layering size changes the value of mechanical properties. The mechanical properties improved for an additional layering size.
(4) The hybrid of the jute-ramie greater in the tensile and flexural properties. Meanwhile, the jute-roselle is superior in terms of impact properties.
(5) The weight content and type of fabric are the dominance properties that influence the mechanical properties.
(6) The effects of stacking sequence are only significant for the flexural properties but are less sensitive for the tensile and impact. For the flexural properties, the hybrid composite with the fabric shows a higher strength at the surface and performs better.
(7) The water absorption has an adverse effect on the tensile properties. The tensile strength and tensile modulus suffer the loss of strength and flexibility greatly when it is immersed in distilled water. The void content influences the performance of the tensile properties.

Lastly, it can be concluded that the woven jute, ramie and roselle are excellent reinforcements for UPE resin. The mechanical properties for monolithic and hybrid composites for jute, ramie and roselle are acceptable and suitable for high-load bearing applications. Nevertheless, further investigation should be conducted especially in terms of dispersion and fibre/matrix adhesion via SEM observation. The implementation of additive in polymer matrix composite and surface treatment for natural fibre reinforcement is required to improve the mechanical properties and resistance to moisture for the samples results of this study indicates that the mechanical properties of the composite reinforced by silk fibre are interesting and they are few affected by the orientation of fibres. Moreover, the silk fibres have better interaction with the matrix and better wetting.

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